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7/11/97

TO: Bruce Franca, FCC

cc: Martin Leader David Smith RECEIVED

JUL 14 1997

FROM: Nat Ostroff

FEDERAL COMMUNICATIONS COMMISSION
OFFICE OF THE SECRETARY

SUBJECT: DTV power and attached paper

It thought you see the attached paper. It deals with the effect on coverage of the DTV station when an indoor antenna and a 10db N.F. receiver is considered. In particular the impact of a 1000kw signal vs a 50kw signal should be noted. It is this difference that we in the UHF community are having a hard time accepting. We don't think that today's NTSC reception situation is reflected in the DTV reception as shown in these maps.

Competitively, we think that, the effect of the 50kw vs 1000kw power levels in the same market is to create two classes of stations that are not the same as today's VHF vs UHF stations inside of the Grade A contour.

This is a serious concern of many in the UHF industry and I hope that we will be able to meet with you in the very near future to discuss this further.

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SINCLAIR BROADCAST GROUP

June 30, 1997

Dear Member of the UHF Broadcast Industry.

Attached is a copy of a paper that was just completed. It addresses the problem of the low power assignments that the FCC has given to most UHF stations in major markets. Sinclair Broadcast Group has done a number of computer studies as well as researched the literature on the subject of UHF propagation. This paper summarizes some of those findings. Of particular interest is the fact that the FCC did not consider any indoor antenna reception of the DTV signal. The results of Sinclair's studies are that indoor antenna reception of UHF DTV signal requires a much higher power than is currently being assigned to many UHF stations. The paper illustrates just how disadvantaged the UHF industry is with respect to reception inside of its Grade A contour when realistic indoor receiving models are explored. In fact, in the study in the paper the UHF station loses more households than its VHF/UHF competitor inside of the Grade A when indoor antennas are used for reception of DTV signals. This situation can be expected to be true in most markets where the UHF is assigned 50kw and the UHF/VHF is assigned 1000kw.

Sinclair is attempting to bring this unfair and threatening situation to the attention of the UHF industry. Please feel free to distribute this letter and the associated paper.

Sincerely

Vice President - New Technology

FCC DTV PLANNING FACTORS WILL RESULT IN A HUGE LOSS OF HOUSEHOLDS FOR 50KW UHF DTV STATIONS 6/30/96

N.S. OSTROFF

Vice President, Sinclair Broadcast Group

INTRODUCTION:

The FCC planning factors are both unrealistic and ignore the reality of today's reception environment. By doing so the FCC is about to place the UHF industry at a huge disadvantage with respect to the VHF industry in the DTV world. This report will detail the nature of the problem by using a typical station operating at 50kw and compare its coverage to the FCC predicted coverage using various assumptions about the real path losses that are possible. In addition this report will compare the coverage achieved by the 50kw UHF DTV station against a VHF station operating at 1000kw that is using the same antenna and tower site.

WHAT IS WRONG WITH THE FCC PLANNING FACTORS?

The FCC planning factors are far too optimistic in several area. They also ignore the indoor reception problem completely. The indoor reception problem is critical because there are no assurances that the cable companies will carry the DTV signals until a large market penetration of receivers is achieved. In the formative years of the DTV service, with no cable carriage, we can only rely on over-the-air delivery of our DTV product.

The FCC planning factor for receiver sensitivity sets the UHF receiver at twice the sensitivity of a VHF receiver. This flies in the face of today's reality that VHF receivers are always more sensitive than their UHF counterparts. A more realistic assumption would be to place the UHF receiver at least equal to the FCC assumption for the VHF receiver in DTV. That is a Noise Figure (NF) of 10db instead of the current assumption of 7db.

The FCC planing factor assumes that ALL reception will be from an outdoor antenna, without a preamplifier, on a 30 foot mast. There is no assumption of any indoor reception applications or in home coaxial wiring systems (see Appendix). If indoor reception is considered, a typical antenna would be a "loop" or "bow tie". These antennas have no gain. That is, their gain is 0db. The outdoor antenna assumed by the FCC is assigned a gain of 10. That is 10db. The down lead losses from the outdoor antenna is assigned by the FCC planning factors at a little over 50% of the incoming signal. That is 4db. There is no FCC assumption of losses for penetration of the building walls to reach the indoor antenna.

A report done by Ga. Tech. in 1980 (see appendix) established the UHF signal losses for a cinder block building with no metal in its walls, roof or windows, at 30db. That is, 1000 times less signal power is received inside the building as is available to the same antenna outside of the building. This is a very critical piece of information that was not included in any planning scenarios published by the FCC in its DTV proceedings, even though it was available to it since 1980.

REALISTIC INDOOR ANTENNA PLANNING FACTORS:

Assume an indoor antenna. The signal reaching it will have to penetrate the walls of the building. These walls will include metal clad insulation, electrical wiring and metal pipes, as a minimum. Therefore, a choice of the Ga. Tech penetration losses of 30 db seems reasonable, if not optimistic. The indoor antenna gain is 0db but there is no downlead lead losses. Finally the UHF receiver Noise Figure should be at least as good (bad) as a VHF receiver of 10db. Therefore the following planning factors result:

FCC Factors	Indoor Factors	Net change to path loss
Receiver N.F.= 7db	Receiver N.F. = 10db	3db
Down lead losses = 4db	Downlead losses = 0db	-4db
Receiver Ant. Gain = 10db	Receiver Ant gain = 0db	10db
Building loses N/A	Building losses = 30db	30db
Net Overall Change in Plann	ing Factors for path loss:	39db

The table above shows how the calculated path loss to an outdoor antenna used in the FCC planning factors needs to be increased to develop an equivalent model for indoor reception. In short, the combination of building losses and low gain indoor receiving antennas amounts to an additional loss of 39db over the FCC planning factor.

APPLYING THE INDOOR PLANNING FACTORS TO ACTUAL COVERAGE:

A series of coverage maps is attached to this report. These maps were developed by the Department of Commerce, ITS, in Bolder Co. The intent of the map series is to look at a typical station, in this cast WPGH in Pittsburgh Pa and study the impact of the indoor planning factors. In addition the series of maps can be used to illustrate the advantage a VHF station moving to a UHF DTV channel at 1000kw has over its UHF competitor operating at only 50kw in the indoor receiving model.

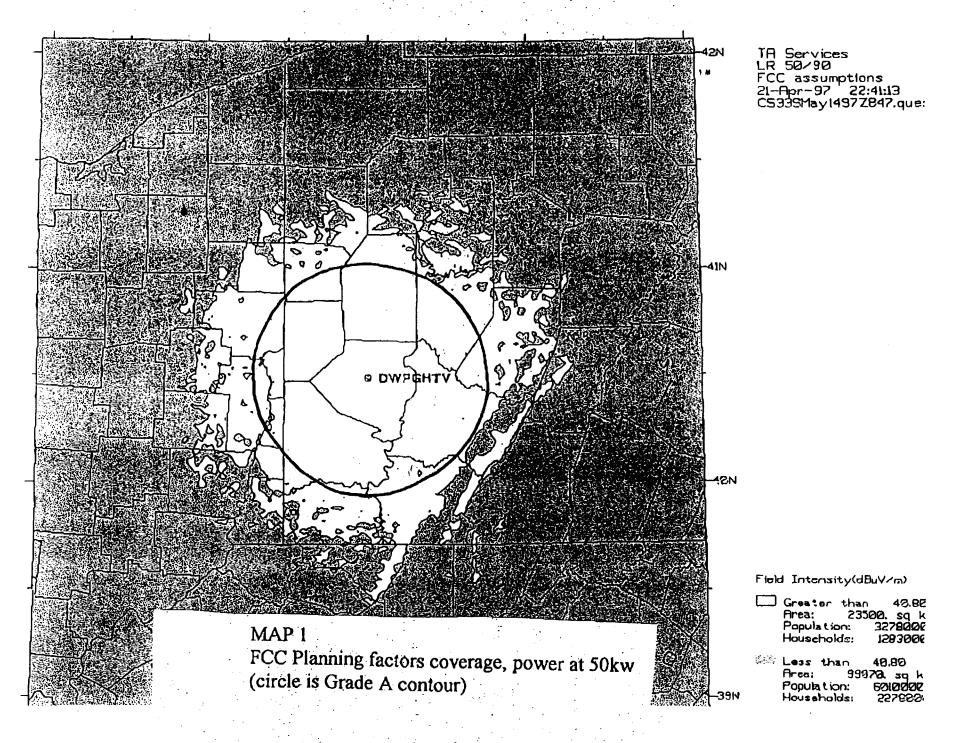
Map #1 is the coverage of DWPGH using the FCC planning factors with no adjustment. That is, an outdoor antenna at 30 feet and a receiver N.F. of 7db. The circle represents the stations Grade A contour in the analog world. In this example all of the Grade A is covered as expected.

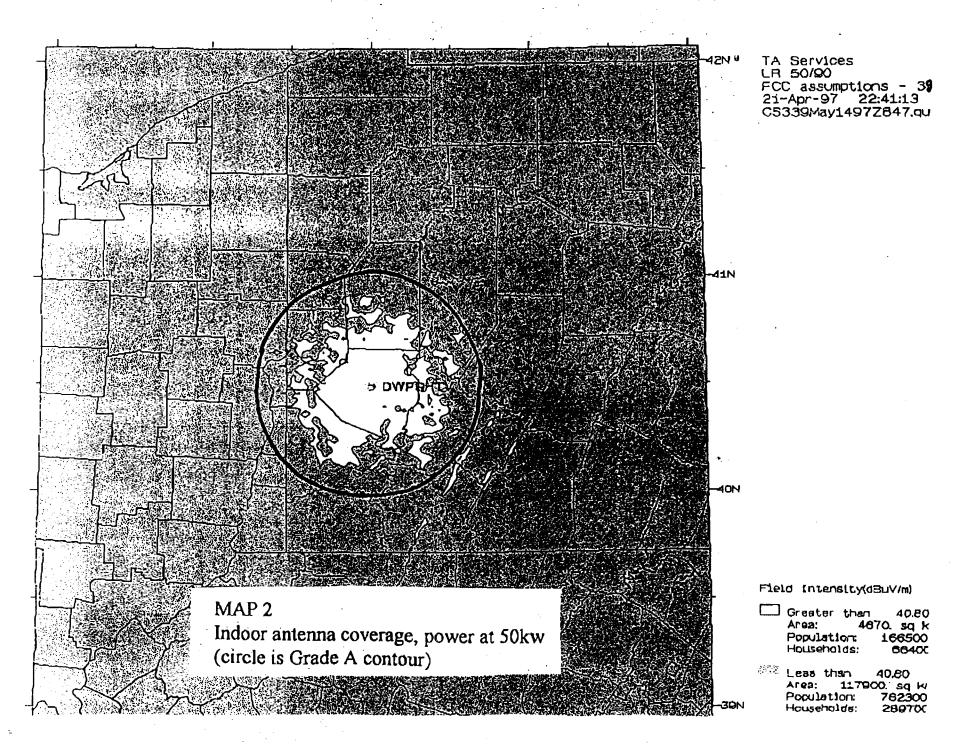
Map#2 is the coverage that can be expected for indoor antennas using the planning factors developed above. In the example at least 48% of the households in the market cannot receive the signal with indoor antennas. More importantly, all of the Grade B is lost and virtually 50% of the Grade A is lost to indoor antennas.

Map#3 is the coverage that can be expected if the power level of the station were set at approximately 1000kw. This example represents the situation for a VHF station moving to UHF DTV at 1000kw. The map shows how the Grade A is filled out and some Grade B coverage is actually achieved. More importantly the number of households that can receive the 1000kw station using indoor antennas is fully 30% above those that can receive the UHF 50kw station. In other words, the UHF DTV station has disenfranchised a significant number of its viewers inside of its Grade A contour compared to the VHF/UHF DTV station.

CONCLUSIONS:

The current FCC planning factors create an unfair disadvantage to the UHF industry in DTV. The much higher powers that are assigned to the VHF/UHF stations, which were intended to allow replication of their Grade B contours, give these very same VHF/UHF stations a very large competitive advantage inside of the Grade A contour for indoor receiving antennas. This advantage is unfair and unwise since it sets up a situation in which a large number of households will be disenfranchised and therefore will not find DTV an attractive alternative to Analog TV. In short, an unfair distribution of DTV power may very well sow the seeds of its failure with the American consumer.





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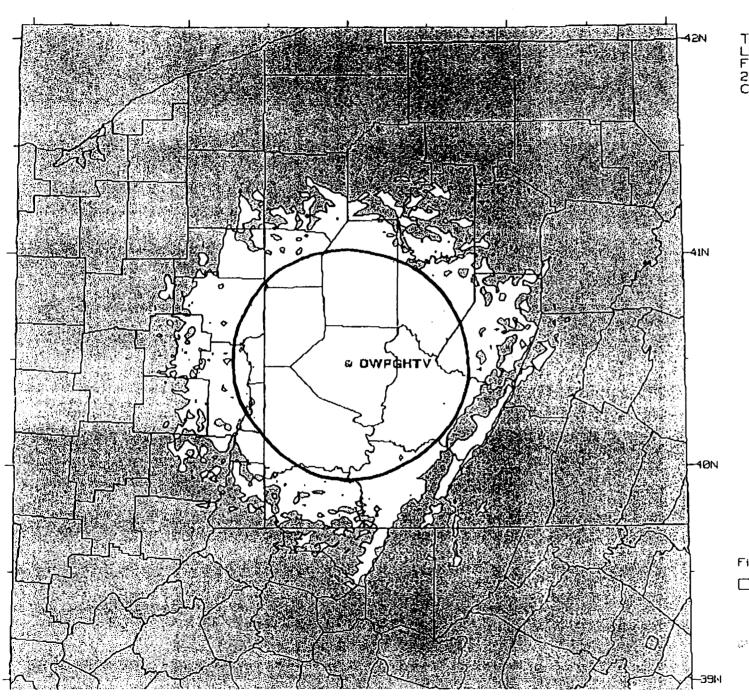


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113010. sq kr fort: 709800 ilde: 289100 Population: Householde:

MAP 3 Indoor Antenna Coverage, power is 1000kw (Circle is Grade A)

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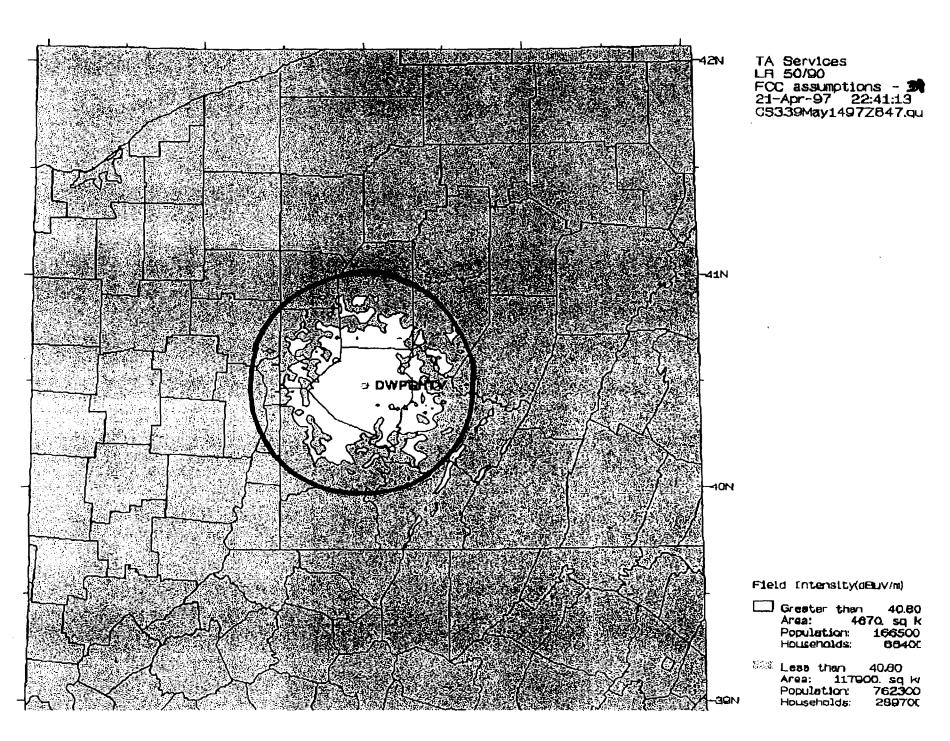


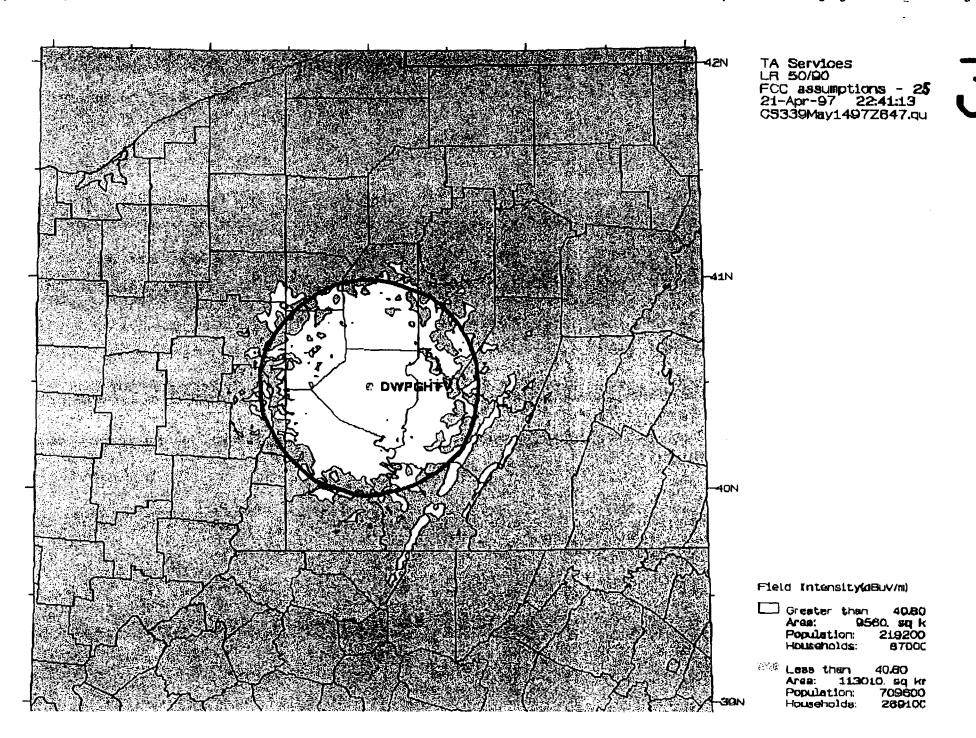
TA Services LR 50/90 FCC assumptions 21-Rpr-97 22:41:19 CS339May1497Z847.que:

Field Intensity(dBuV/m)

Greater than 40.92 23500. sq k n: **3**278000 Area: Popula tion: Householdsi 1203000

n 40.80 99070, sq k n: 6010000 ls: 2278001 🚉 Less than Area: Population: Households:





APPENDIX TO FCC PLANNING FACTORS.... 6/30/97

- Program to Improve UHF Television Reception..(excerpt)
 Georgia Institute of Technology
 September 1980
 FCC Contract Number FCC-0315
 Project No. A-2475
- 2. Analog coverage map of WPGH ch. 53
- 3. Digital Transmission Over In Home Coaxial Wiring Kerpez, et al
 IEEE Transactions on Broadcasting
 June 1997

FINAL REPORT
PROJECT NO. A-2475

PROGRAM TO IMPROVE UHF TELEVISION RECEPTION

BY

W. R. Free

J. A. Woody

J. K. Daher

Prepared for

UHF COMPARABILITY TASK FORCE OFFICE OF PLANS AND POLICY FEDERAL COMMUNICATIONS COMMISSION WASHINGTON, D.C. 20554

Under Contract No. FCC-0315

SEPTEMBER 1980

GEORGIA INSTITUTE OF TECHNOLOGY



Engineering Experiment Station Atlanta, Georgia 30332



line is twin-lead instead of coax. The performance of System 5 is degraded relative to System 4.

11.2 Indoor System Measurements

Measurements were also made to evaluate the relative performance of antenna/transmission line systems when all or part of the system is located indoors. As indicated by the relative performance of System 7 in the previous section, the use of an indoor antenna, even with a preamplifier, requires approximately a 30 dB* increase in the power density of the field on the building to achieve system performance comparable to that of an outdoor system. The effective building attenuation, including multiple reflections, as well as the antenna gain affects the required power density.

The building at the antenna test range is constructed of concrete blocks with no metal in the walls, roofs, and doors. In order to determine potential effects of this type of building on indoor antenna/transmission line systems, the signal received with only the indoor antenna of System 7 was measured with the antenna located both indoors and outdoors (on the roof). The received signal level outdoors was 28.1 dB greater than the indoor received level. Thus, to achieve comparable system performance, the effective building attenuation can increase the power density required by approximately 28 dB.

As a final evaluation of performance indoors versus outdoors, only part of the system, i.e., the preamplifier, was moved indoors. Normally, the preamplifiers in Systems 1 through 6 in Section 11.1 were located at the antennas with their power supplies located at the TV receiver. Since the preamplifier is prior to the transmission line, the transmission line will attenuate the noise generated at the preamplifier and the signal equally. In contrast, when the preamplifier is located at the TV receiver, the transmission line which is now prior to the preamplifier will attenuate the signal but not the noise generated at the preamplifier. Thus, relocating the preamplifier indoors should necessitate

^{*} It is noted that the numbers in this section may vary a few dB if the location of the indoor antenna in the building is changed.

TABLE 11-2

POWER DENSITIES OF THE FIELD REQUIRED TO OBTAIN A 30-dB S/N RATIO AT THE OUTPUT OF THE SYSTEM-UNDER-TEST

System Number	Power Density	Change	Cost
	(dB_m/m^3)	(dB)	
1	-79.0	0.0	\$259.31
2	-75.6	3.4	223.07
3	- 74.8	4.2	200.33
14	-74.6	4.4	55.39
5	-69.8	9.2	55.78
6	- 71.8	7.2	58.19
7	-43.2*	35.8	46.90

Note that System 7 is an indoor system. Thus, the building attenuation at the test site (approximately 28 dB) is included in the power density required.

Pennsylvania—Pittsburgh

WPGH-TV.

Ch. 53

Network Service: FOX.

Licensee: WPGH Inc., 750 Ivory Ave., Pittsburgh, PA 15214-1606.

Studio: 750 Ivory Ave., Pittsburgh, PA 15214-1606.

Phone: 412-931-5300. Fax: 412-931-8135.

Technical Facilities: Channel No. 53 (704-710 MHz). Authorized power: 2340-kw max. & 1280-kw horizontal visual, 234-kw max. & 64-kw horizontal aural, Antenna: 1010-ft, above av. terrain, 736-ft, above ground, 2049-ft, above sea level.

Latitude 40° 29' 43" Longitude 80° 00' 18"

Holds CP for change to 1024-ft, above av. terrain, 702-ft, above ground, 2021-ft, above sea level, lat. 40° 29' 43", long. 80° 00' 17" BPCT-930708KF.

Requests modification of CP for change to 5000-kw max. visual. BPCT-950629KP.

Transmitter: 750 Ivory Ave., Pittsburgh.

Satellite Earth Stations: AFC, 3.7-meter C-band; AFC, 4.5-meter Ku-band; AFC, 4.7-meter C-band; AFC 7.3-meter C-band; SatCom, 5.5-meter C-band; Vertex, 6.1-meter C-band; DX Communications, Harrls, MA-Com, Microdyne receivers.

LMA: Local marketing agreement with WPTT-TV (U), Pittsburgh.

Ownership: Sinclair Communications Inc. (Group Owner).

Began Operation: July 14, 1953. Started as WKJF-TV. left air July 2, 1954. Resumed operation under new ownership Feb. 1, 1969; left air Aug. 16, 1971. Transfer to Henry Posner Jr. from Receiver in Bankruptcy approved Dec. 12, 1973. Returned to air Jan. 14, 1974. Sale to Meredith Corp. by Henry Posner Jr. approved by FCC Sept. 8, 1978 (Television Digest, Vol. 18:17, 38). FCC approved sale by Meredith to Lorimar-Telepictures Nov. 12, 1986 (Vol. 26:29, 46, 52; 27:2). Sale to Renaissance Communications approved Nov. 23, 1988 (Vol. 29:3). FCC approved sale to present owner June 21, 1991.

Represented (sales): Petry Television Inc.

Represented (legal): Fisher Wayland Cooper Leader & Zaragoza L.L.P.

Personnel:

Alan B. Frank, General Manager.

John Rossi, Director of Sales.

Kevin Moylan, General Sales Manager.

Terry Caywood, Director of Operations & Programming.

David Janecek, News Director.

Bill Hansen, Chief Engineer.

Wendy Shust, Business Manager.

Melissa Stone, Promotion Manager.

Michael Wolft, Director of Marketing & Advertising.



WPGH-TV BPCT-930708KF Granted 10/26/94 @ American Map Corp., No.:14244

Rates: On request.

City of License: Pittsburgh, Station DMA; Pittsburgh, Rank: 19.

Circulation @1996 Nielsen, Coverage based on Nielsen study

Grand Total	Cable TV Households	Non-cable TV Households	Total TV Households
Estimated Station Totals*	1,281,870	337,650	1,619,520
Average Weekly Circulation (1996)	671,444	109,189	780,634
Average Daily Circulation (1996)		·	322,639

Station DMA Total	Cable TV Households	Non-cable TV Households	Total *** TV Households
Estimated Station Totals*	893,880	251,020	1,144,900
Average Weekly Circulation (1996)	537,693	94,379	632,073
Average Daily Circulation (1996)	·		265,596

Other DMA Total	Cable TV Households	Non-cable TV Households	Total Total Tylography VT
Estimated Station Totals*	387,990	86,630	474,620
Average Weekly Circulation (1996) Average Daily Circulation (1996)	133,751	14,810	148,561 57,043

"Estimated station totals are sums of the Nielsen TV and Cable TV household estimates for each county in which the station registers viewing of more than 5% as per the Nielsen Survey Methods.

BEEF TRANSACTIONS ON BROADCASTING, VOI. 43, NO. 2, JUNE 1997

36

DIGITAL TRANSMISSION OVER IN-HOME COAXIAL WIRING

Kenneth J. Kerpez, Thomas E. Chapuran, Ronald C. Menendez, and Stuart S. Wagner
BELLCORE, 445 South St., Morristown, NJ 07960

Chabstract - The wiring of a customer's premises network (CPN) may be the weakest link in the end-toend transport of residential broadband digital services such as digital video. Detailed knowledge of how such premises wiring will affect digital service delivery is critical to the cost-effective deployment and robust operation of digital technologies. This paper reports selected results from a series of experimental and analytical studies of coaxial-cable premises-wiring impairments for digital broadband signals. The investigations included return loss, isolation and attenuation measurements of a wide variety of components, as well as measurements and simulations of bit-error-rate performance for several inside-wiring test-bed configurations. The components showed a broader range of performance, and in some cases considerably worse performance, than indicated in previous studies. The premises wiring generated signal reflections which can severely degrade digital transmission. Some reflections can cause destructive interference that effectively decreases the received signal power by 10 dB more than the nominal attenuation, and this decrease is not mitigated by settop or cable-modem adaptive equalization.

I. INTRODUCTION

In-home, customer-premises wiring represents one of the weakest links in the end-to-end delivery of residential broadband services. The quality of digital video or data services can be seriously degraded by ingress, impulse noise, signal reflections, and limited bandwidth or excessive attenuation in premises wiring.[1-3] The resulting signal impairments can vary widely from one home to another as a result of differences in inside-wiring topology, component installation practices. quality and characteristics are not under the control of the service provider, and are likely to change over time as customers modify their wiring configurations.

A central question is the degree to which transmission impairments in premises wiring are likely to degrade service quality, potentially requiring changes in wiring, installation and maintenance

This paper was presented in part at the Twelfth Annual National Fiber Optic Engineers Conference, NFOEC '96, Denver, September 8-12, 1996.

procedures, or network design. These issues are relevant to a wide range of broadband digital networks, including terrestrial digital broadcasting, satellite, multichannel multipoint distribution service (MMDS), local multipoint distribution service (LMDS), hybrid fiber/coax (HFC), and switched digital video (SDV).

This paper addresses impairments in coaxialcable customer premises networks (CPNs), and includes selected results from a series of measurements and simulations covering both component performance and the overall system impact on digital transmission. The focus here is primarily on signal reflections, which are shown to be capable of producing severe degradations. We identify one important class of static reflections which is not mitigated by adaptive equalization. More generally, the data and the underlying models developed in the course of this work can be applied to a wide range of access network technologies and inside-wiring topologies. This should be helpful in developing guidelines for new CPN installations, for determining when to repair or replace existing wiring, and for establishing installation and maintenance procedures to ensure service quality.

Section II briefly reviews existing broadband inside-wiring networks and the impairments which they can generate for digital signals. Section III focuses on the origins of signal reflections, and provides illustrative results from component performance studies. Section IV presents experimental investigations of the impact on system-level performance for digital transmission. Section V presents computer simulations of digital transmission on coaxial inside-wiring. Section VI contains further discussion and conclusions.

II. CUSTOMER PREMISES NETWORKS (CPN)

It is often assumed that new broadband services, such as digital video broadcasting or high-speed data delivery, will re-use existing premises wiring to minimize installation cost and subscriber inconvenience. The coaxial video-distribution network found in most homes is a natural candidate, due to its high bandwidth and its existing routing to one or more TV-viewing locations. New or replacement wiring would be similar, except for the use of more modern cable and components. Alternative

approaches have been proposed to improve the transmission performance, but typically require additional gateway electronics at the entrance to the home [4] (e.g., to select the signals of interest and remodulate them in a more robust format), or a combination of gateway electronics and new premises wiring. Therefore it is important to determine under what circumstances traditional premises wiring will be adequate for carrying digital signals.

A typical video CPN might connect incoming video through a 1:2 splitter to a cable-ready TV and to a second TV utilizing a digital set-top box (STB). The cable itself is usually RG-6 or RG-59 coax. Coaxial Fconnectors are used at every interface, i.e., at the ground block, splitter ports, wall plate, TV and settop, and wherever jumpers have been added. Additional equipment may also be connected, such as VCRs, cable/antenna switches, FM traps (which separate video and FM bands), or video-game equipment. Many installations today consist of a 1.2 splitter serving two outlets, or even a single cable directly connected to one TV. This may well be inadequate for future services, given the growing interest in additional connections for personal computers, and the fact that one-third of US households now have at least three TVs. [5]

The condition of the CPN depends strongly on its original installation and its subsequent history. A wide range of component quality and installation practices must be expected. [6,7] Cables and connectors can deteriorate with age, and older systems are also likely to have lower-bandwidth components. The wiring may well have been modified or reconfigured by the residents.

Good performance for analog video does not ensure adequate quality for digital signals [8] Most broadband digital networks will operate at higher and/or lower frequencies than traditional one-way cable systems. The CPN is the major entry point for ingress and impulse noise, which is especially pronounced in the low-frequency bands (i.e., < 40 MHz) now being activated. At higher frequencies, limited bandwidth or excessive attenuation can severely limit signal quality, as the digital bit-error rate (BER) degrades more abruptly than the analog carrier-to-noise ratio (CNR) with reductions in the received signal power.

Digital transmission is also strongly affected by small signal reflections (commonly referred to as microreflections in the cable-industry literature), which would not be noticeable with analog video. Signal distortion due to static reflections can be reduced by adaptive equalization. Equalization adds cost and complexity to set-top converters and high-speed modems, and must be designed to accommodate realistic reflection amplitudes and time delays. Upstream transmission is generally less amenable to

this approach, due to the complications introduced by multiple-access systems. Time-varying reflections (such as those which can be caused by channel surfing on a TV connected to a different output port of the splitter connected to the digital receiver) are difficult to compensate with equalization, and can cause signal loss and gaps in real-time transmissions.

The remainder of this report focuses on signal reflections, which represent one of the most common CPN impairments.

III. COMPONENTS CAUSE REFLECTIONS THAT CAUSE ECHOES

As signals propagate, they encounter an impedance mismatch at every cable connector and component interface. Each mismatch causes a portion of the signal to be reflected and travel in the opposite direction. Two successive changes in direction can produce an echo, i.e., an attenuated and delayed replica of the signal, transmitted in the same direction. Echoes interfere with detection of the main signal, which travels directly to the receiver.

Figure 1 illustrates the two most common mechanisms for generating echoes in the CPN. Echo path 1 corresponds to a signal which is reflected twice in succession, by two different devices (in this example, the set-top converter and the two-way splitter). At each interface, the power in the reflected signal is attenuated by an amount equal to the return loss of the interface. The return loss, measured in dB, is the ratio of the incident signal power to the signal power which is reflected. A perfect, non-reflecting interface would have an infinite return loss, while a total 100% reflection (e.g., from an open or shorted cable) would correspond to a return loss of 0 dB. The echo corresponding to path 1 is thus attenuated at both reflection points, and is further attenuated (relative to the direct signal) as a result of the longer distance which it travels through the cable.

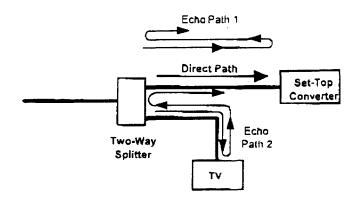


Fig. 1. Two types of echo paths which can interfere with the signals passing directly to the digital set-top converter.

Echo path 2 is an example of an echo generated by a single reflection point. In this case, inadequate isolation between the output ports of the splitter causes part of the signal reflected from the TV to be funneled into the other branch, leading to the set-top converter. The isolation, measured in dB, is the ratio of the signal power incident at an output port to the signal power which emerges from a different output port. A splitter with no cross-coupling between output ports would have an infinite isolation, while a splitter with complete coupling between output ports would have an isolation of 0 dB. The echo corresponding to path 2 is thus attenuated by the return loss at the TV, the isolation of the splitter, and the loss of the additional cable traversed.

Echo path 2 is often of particular concern, for two reasons. First, very large (0 dB) reflections can be generated on the lower branch in Fig. 1, if the cable is disconnected from the TV and left unterminated. In this case, the splitter isolation is the only reliable defense against large echoes on the other branch of the network. Secondly, with the TV connected, echo path 2 represents a major source of time-varying echoes. The input impedance of a TV is typically wellmatched to 75 Ω only at the frequency to which the TV is tuned. At other frequencies the TV's return loss can be nearly 0 dB.[9] Furthermore, the return loss varies strongly with frequency. As a result, channelsurfing on the TV can generate strong, time-varying echoes at the (fixed) frequency being accessed by the set top on the other branch.

Since the size of the echoes depends so strongly on component properties, it is critical to know the full range of component performance which is likely to be encountered. Previously published studies [7] have provided valuable information on component performance, but have typically been limited to a very small sampling of devices (e.g., six 1:2 splitters, most with 600 MHz bandwidth). For this project, a wide variety of components was obtained, from equipment utilized by cable-television service providers, to components available at electronics stores and other retail outlets. This included roughly two dozen splitters, both 1:2 and 1:4 varieties, rated for operation at 600 MHz, 900 MHz and 1 GHz. Attenuation, return loss and isolation were measured over a range of 300 kHz to 1 GHz.

A sample of the results is presented here. Figure 2 presents the isolation performance (important for echo path 2) of several 1:4 splitters, all rated for operation to either 900 MHz or 1 GHz. Note that a splitter with 10 dB isolation will pass 10% of the signal power incident at one output port to the second output port. A splitter with 20 dB isolation (the worst-case value reported in [7]) passes only 1% of the signal power between output ports.

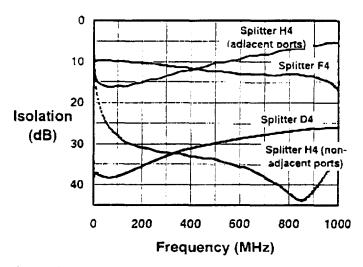


Fig. 2. Output-port isolation as a function of frequency for several 1:4 coax splitters, rated for 900 MHz or 1 GHz bandwidth.

The curves in Fig. 2 show a very wide range of performance. The two top curves show splitters which exhibit isolations well below 20 dB over their entire frequency range. The isolation of splitter F4 is no greater than 10 dB from 5 MHz to 140 MHz. The isolation of splitter H4 is less than 10 dB from 540 MHz up to the top rated frequency of 900 MHz, where it falls to only 6 dB. On the other hand, splitter D4 maintains a high isolation of at least 26 dB at all measured frequencies.

For comparison, 20-25 dB of isolation is typically provided between output ports of a coaxial multi-tap, which is used to supply signals to multiple subscriber drops. A previous study [7] of six 1:2 splitters had reported port-to-port isolations exceeding 20 dB over their full rated bandwidth (600 MHz or 1 GHz), and an earlier study [9] had reported a worst-case isolation of 15 dB for an unspecified number of splitters (apparently including 1:4s).

Splitter isolation can be measured between any pair of output ports. In some cases, significant differences were observed depending on the particular pairs of ports that were measured. With splitter H4 in place, Fig. 2 shows that the network performance could depend substantially on which specific splitter ports were connected to the equipment of interest. This is important to keep in mind when troubleshooting an existing premises network.

The return loss of the components was also measured, and a sample of these measurements is shown in Fig. 3. Return loss measurements were made with all unused ports terminated (in 75 Ω). Here again a wide range of performances was observed. The return loss of the worst component was as low as 3 dB, meaning that half the signal power was reflected.

Other components had return losses exceeding 20 dB at all measured frequencies.

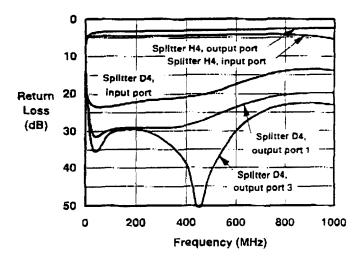


Fig. 3. Return loss as a function of frequency for several 1:4 coax splitters, rated for 900 MHz or 1 GHz bandwidth.

In general, our measurements of isolation, return loss and attenuation covered a wide variety of components, including many 1:2 and 1:4 splitters, and indicated that there is a broader range of performance, and in some cases considerably worse performance, than has been previously noted. [7,9] The worst overall performance of a 2-way splitter measured at a single frequency from 5-1000 MH2 was 5 dB attenuation, 12 dB isolation, and 5 dB return loss. The worst overall performance of a 4-way splitter measured at a single frequency from 5-1000 MHz was 15 dB attenuation, 6 dB isolation, and 3 dB return loss. These numbers are exceptionally poor. On the other hand, quite a few components exhibited excellent performance and should not degrade digital signals. It is interesting to note that even simple components such as ground blocks and wall-plates can cause reflections; these components all had about 33 dB return loss at 50 MHz, 20 dB return loss at 300 MHz, and 12 dB return loss at 700 MHz.

Components tend to fall into groups on the basis of their measured performance. However, labels such as "CATV industry products" and "retail products" [7] are not always good predictors of performance. For example, one type of 1 GHz-rated cable-industry 1:2 splitter which was measured exhibited performance in critical tests which was comparable to the lowest-performance retail splitter.

IV. EXPERIMENTS OF DIGITAL TRANSMISSION ON COAX INSIDE-WIRING

Having examined the range of inside-wiring component characteristics that are encountered in residential CPNs, we next investigated the resulting impact on digital transmission performance. To quantify this impact, a number of CPN "test configurations" were developed, representing a range of component quality and likely wiring topologies. The configurations with good components had little impact on digital transmission, so the results for them are not displayed here. This paper instead concentrates on the configuration with the poorest characteristics.

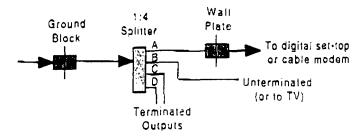


Fig. 4. One of several test configurations used to investigate premises-wiring impairments.

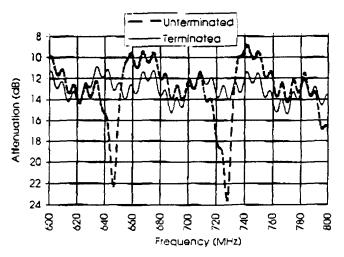


Fig. 5. The response of the test configuration in Fig. 4, with a 5-ft cable connected to output port B which is both with and without a 75 Ω termination.

Figure 4 shows this test configuration. From left to right, the set-up consists of a ground block, a four-way splitter and a wall plate, followed by a receiver (representing a digital set top or data modem). The splitter is a retail device (splitter H4 in Figs. 2 and 3) exhibiting high insertion loss (10 dB), low return loss (3 dB at the output port) and low isolation (8 dB), where the quoted performance was measured at 700 MHz. This splitter represents a worst case, but it is not at all unusual and was in fact one of the most

commonly available retail products in our area at the time this work was performed. Unused splitter ports C and D are terminated in 75 Ω . Port B is connected to either terminated or unterminated cables of varying lengths, to create reflections with different time delays and magnitudes (in addition to the many other reflections which take place between the ground block, splitter and wall plate). Figure 5 shows the measured magnitude response of this configuration at high frequencies with a 5-ft cable connected to port B. Notice the deep null at 728 MHz when the 5-ft cable is unterminated.

Bit-error-rate (BER) performance was measured as a function of the signal level at the entrance to the home (i.e., at the ground block) using a commercial 64-QAM modulator and demodulator operating at 30 Mbps. With 6 bits represented by each 64-QAM symbol, this corresponds to a rate of 5 Mbaud (5 million symbols per second). The demodulator contained a 16-tap adaptive equalizer, and the system error correction. The experimental configuration allows for BER testing over a wide span of carrier frequencies of interest in future digital networks, such as the 550 MHz to 750 MHz region frequently targeted for downstream digital transport over HFC networks. Quantifying BER performance as a function of the signal level at the CPN input, rather than at the input to the digital receiver, provides a more-direct measure of power penalties due to the inside wiring.

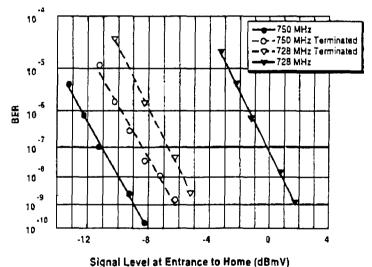


Fig. 6. BER measurements for 64-QAM transmission through the premises wiring test configuration in Fig. 4, at 728 MHz and 750 MHz, with and without termination at the end of a 5-ft cable connected to splitter port B.

Figure 6 shows BER curves for the configuration of Fig. 4 at two different carrier frequencies, with

either terminated or unterminated 5-ft cables connected to splitter port B. One might expect relatively little variation in BER performance across the ~20 MHz range of frequencies shown in the figure. since the nominal cable and splitter attenuations are roughly constant across this region. However, when the 5-ft cable was left unterminated (a common occurrence in today's CPNs), changing the carrier frequency from 750 MHz to 728 MHz increased the CPN input signal-level requirement by nearly 11 dB. Terminating the 5-ft cable eliminated the strongest echoes in the transmission, reducing the BER variations with frequency, and improving the performance at 728 MHz by roughly 7 dB. Note. however, that terminating the 5-ft cable actually degraded the BER performance at 750 MHz.

This wide variation of BER with carrier frequency is the result of carrier interference effects that arise from strong short-time-delay echoes within the CPN. The relative phases of the carriers for the direct and reflected signals arriving at the digital receiver's input will depend on the carrier frequency and on reflection path lengths (i.e., on the lengths of CPN cables). For a prescribed set of cable lengths, a given echo will arrive in phase at certain frequencies, producing constructive interference, but will arrive 180 degrees out of phase at certain other frequencies, causing destructive interference. In our test configuration, the strong reflection from the 5-ft cable produces destructive interference which leads to deep nulls in the frequency response, including a null at MHz. On the other hand, constructive interference from the various reflections in the system occurs at 750 MHz, which explains the improved performance when the cable is left unterminated. The exact positions of peaks and nulls in the CPN frequency response depend on the cable lengths, which of course will vary from one home to another. Since the echo from the 5-ft cable has a short delay (-3% of the 64-QAM baud period), it was not eliminated by the adaptive equalizer.

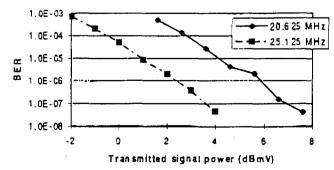


Fig. 7. BER measurements for 16-QAM transmission through the premises-wiring test configuration in Fig. 4, at 20.625 MHz and 25.125 MHz, with a 40 ft unterminated cable connected to splitter port B.

Transmission was also tested with frequencies and modulations typical for upstream transmission on cable TV networks such as HFC. A 16-QAM modulator and demodulator operating at the DS1 rate of 1.544 Mbps was used to send signals over the configuration in Fig. 4. Here the modulated signal has 100% excess bandwidth, and occupies 772 kHz of bandwidth. 16-QAM signals from the transmitter were injected into the inside-wiring test configuration. After passing through the inside wiring, the signals were sent to the 16-QAM receiver. A constant noise level was injected at the input to the receiver, which represents upstream reception of ingress and other noises from multiple sources. The receiver contained no adaptive equalizer, and no forward error correction.

The configuration in Fig. 4 was used with a 40-ft unterminated cable connected to the splitter output port B. A 40-ft cable was used here since the 5-ft cable did not create a notch in the configuration's magnitude response below 40 MHz. Carrier frequencies were chosen near a peak (25.125 MHz) and near a valley (20.625 MHz) of the configuration's magnitude response. The results of the 16-QAM experiments, shown in Fig. 7, indicate about a 3 dB difference between the two frequencies in the required transmit signal power for a fixed BER and a fixed received noise power. This difference, while significant, is much less than that observed at the higher-frequencies used with 64-QAM shown in Fig. 6.

V. COMPUTER SIMULATIONS OF DIGITAL TRANSMISSION ON COAX INSIDE-WIRING

Detailed computer simulations of digital signal delivery over coaxial CPNs have been developed and successfully tested against experimental measurements. The simulations build on previously reported work. [10] These simulations can determine the impacts of changes in spectrum allocation, modulation technique, component properties, cable lengths, or adaptive equalization. The computer models allow a more expeditious investigation of a broader range of important parameters than could be easily measured in the laboratory.

The simulations can be used to isolate the effects of different types of echoes on digital transmission. Reflections cause echoes that have either of two effects on transmission performance, depending on whether their time delay is long or short. Short-delay echoes are delayed by less than about one symbol period (one baud). Short-delay echoes effectively rotate, and either dilate or compress the received signal constellation. They will decrease the signal strength if they differ in carrier phase from the direct signal by a multiple of 180°. This phase difference is sensitive to changes of just a few fect in propagation

distance. Carrier recovery loops eliminate the phase rotation. However, any signal attenuation caused by the echo will irrecoverably decrease the received signal-to-noise ratio (SNR). In the worst case, the echo is 180° out of carrier phase and it coherently subtracts itself from the received signal voltage. Adaptive equalizers cannot recover the portion of the signal that is canceled by an out-of-phase short-delay echo.

Long- delay echoes are delayed by more than approximately one symbol period. Long-delay echoes can be effectively mitigated by an adaptive equalizer if the delay of the echo is within the span of the equalizer, and if the echo source does not vary rapidly with time. If there is no equalizer, then the distortion engendered by a long-delay echo will become additive noise that increases the BER.

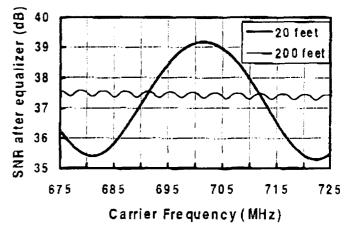


Fig. 8. Signal-to-Noise Ratio (SNR) at the output of the adaptive equalizer, with a single echo, 12 dB down from the direct signal, delayed by traveling an additional 20-ft or 200-ft round-trip path in the coax.

The difference in the effects of short- and longdelay cchoes is illustrated in Fig. 8. This figure shows computer simulation results of a 64-QAM receiver for the idealized case of a single echo, with either a 20-ft or a 200-st round-trip reflection path length. These lengths correspond to 0.1 and 1.1 baud periods, respectively, of the 64-QAM waveform carrying 30 Mbps. Both curves assume adaptive equalization, and both assume an echo amplitude 12 dB down from the direct signal. The short echo produces a 4 dB SNR variation across the range of carrier frequencies considered, while the longer echo causes negligible variation in SNR. In practice, the effects of long-delay echoes are often further reduced by the additional attenuation that usually accompanies the longer propagation lengths.

The simulation result shown in Fig. 8 illuminates the difference between short- and long-delayed echoes, but it is idealized. To mirror real-world conditions, simulations were written that read-in and use the measured response of a wiring configuration.

Simulations of 64-QAM were performed with and without adaptive equalization. The simulated 64-QAM sends 30 Mbps with a baud rate of 5 Mbaud using a raised-cosine pulse with 20% excess bandwidth, and occupies the same 6 MHz bandwidth as a TV channel. The equalizers are 16-tap, complex, baud-spaced, and adapted to minimum mean squared error. The noise power is constant, so it is the same at the transmitter and receiver; but the signal is attenuated and distorted by the inside-wiring, so it has lower power at the receiver than at the transmitter. The SNR is the ratio of the average signal power to the average noise power, where the noise is the sum of Gaussian noise and inter-symbol interference. The BER is calculated by taking the Q-function of the received SNR. The SNR at the transmitter is chosen so that the receiver operates near the limit of acceptable BER. 64-QAM requires 28 dB received SNR for a 10-7 BER with no error correction.

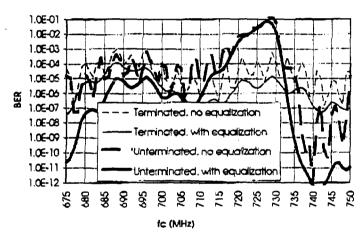


Fig. 9. Simulations of 64-QAM with a 5-ft cable connected to splitter port B which is terminated and unterminated. The SNR at the transmitter is 40 dB.

64-QAM simulation results are shown in Fig. 9. With an unterminated cable and equalization in the receiver, the BER difference as the carrier frequency changes from 750 MHz to 728 MHz corresponds to about an 11-dB difference in input SNR, the same as the experimental findings in Fig. 6. Fig. 9 shows that while equalization improves the performance somewhat, it does not remove the severe degradation at 728 MHz caused by the short-delayed echo.

Simulations were also run with typical modulations for upstream transmission on cable: QPSK and 16-QAM. Notice that QPSK is the same as 4-QAM. The bit rate of simulated QPSK and 16-QAM is 1.544 Mbps and the transmitter sends raised-cosine pulses modulated to the carrier frequency for both. 16-QAM transmits at 386 kbaud with 100% excess bandwidth and occupies 772 kHz RF bandwidth.

QPSK transmits at 772 kbaud with 40% excess bandwidth and occupies 1.1 MHz RF bandwidth. The 16-QAM and QPSK receivers have no adaptive equalizer. A fixed level of noise is injected into the receiver, then the received signal and noise are demodulated to baseband and sampled at the baud rate, and the SNR and BER are calculated the same way as described for 64-QAM. The 16-QAM and QPSK simulations use no equalization.

16-QAM requires 21 dB received SNR for a 10⁻⁷ BER on a flat channel with no reflections. QPSK requires 14 dB received SNR for a 10⁻⁷ BER on a flat channel, 7 dB less than 16-QAM. Figure 10 presents a test case comparing these two modulations, where a 40-ft cable was attached to splitter port B since a 5-ft cable did not create a notch in the configuration's response below 40 MHz. Otherwise, the inside-wiring configuration is the same as previously. Figure 10 shows that 16-QAM and QPSK have essentially identical performance except for their constant difference in required SNR. The approximately periodic change in BER shown in Fig. 10 corresponds to the 3 dB transmit power difference shown in the experimental results in Fig. 7.

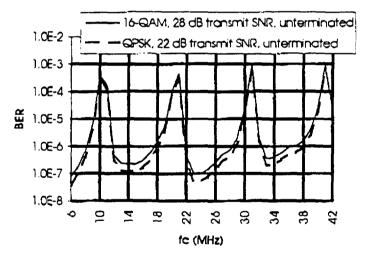


Fig. 10. A comparison of 16-QAM and QPSK transmitted on the configuration of Fig. 4 with a 40-ft unterminated cable connected to splitter port B. No equalization.

Another, more aggressive, technique for upstream transmission on cable is to send 16-QAM signals in high-frequency bands. This was simulated using the configuration of Fig. 4 with a 5 ft cable connected to splitter port B, the same as used with 64-QAM. The results are shown in Fig. 11, which indicates wide swings in performance, including frequency-dependent received SNR variations up to 10 dB.

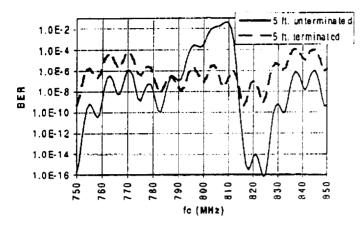


Fig. 11. High-frequency bands for upstream 16-QAM transmission on the configuration of Fig. 4 with a 5-t unterminated and unterminated cable connected to splitter port B. The SNR at the transmitter is 55 dB. No equalization.

VI. DISCUSSION AND CONCLUSIONS

The ability to deliver robust, high-quality broadband digital signals to the home will depend strongly on the quality of the customer-premises network, which is not directly under the control of the service provider or broadcaster. In order to manage this situation, it is critical to have a realistic picture of the range of impairments likely to be encountered, and to establish procedures for overcoming these effects in a cost-effective manner.

The major impairments for digital signals in the CPN are due to ingress, excessive attenuation, and signal reflections. This paper has reported selected results, focusing on reflections, from an extensive series of experimental and analytical studies of component and system-level performance.

The components showed a broader range of performance, and in some cases considerably worse performance, than indicated in previous studies. [7,9] For example, 900-MHz 1:4 splitters can have output port isolation as low as 6 dB at high frequencies, compared with the 20 dB isolation reported in earlier studies using a much smaller sample of splitters. The splitter isolation is directly related to the size of the static and time-varying echoes which will be observed at a digital set top or high-speed modem. Components tend to fall into several categories, based on their overall insertion loss, return loss and isolation performance. However, splitter origin (e.g., cable-industry supplier vs. retail supplier) is not always a good predictor of performance.

Using the component performance results, and a set of reasonable wiring topologies, a number of CPN "test configurations" were developed to represent a range of likely premises-network performance. These configurations were used for experimental performance and measurements computer simulations of the system-level impact of impairments on digital transmissions. It was found that coaxial inside-wiring causes a steady nominal attenuation that varies slowly with frequency, and a rapidly fluctuating attenuation caused by reflective echoes that add in and out of carrier phase with the signal. Results are presented here for the worst test configuration, but it should be noted that the other test configurations did not generate degradations as large as those presented here.

BER measurements were obtained for 64-QAM transmission of 30 Mbps data, as might be used for downstream transmission in an HFC system. Using a test configuration with a poor-quality 1:4 splitter and an unterminated 5-ft cable, destructive-interference effects produced frequency-dependent variations in the received SNR that were greater than 10 dB. This difference was observed at two frequencies separated by only about 20 MHz. The effective attenuation was as high as 23 dB, even though there was only a 1:4 split. These effects can be reduced or climinated in principle through the use of better splitters, although eradication of poor-quality wiring the total components from residential CPNs is probably impractical in the near term.

Computer simulations were developed that can easily examine a wide range of transmission systems and parameters. The simulation results were shown to agree very well with the laboratory experiments. The same frequency-dependent SNR variations of over 10 dB were observed with the simulated 64-QAM.

Typical upstream modulations, QPSK and 16-QAM, were also tested. Experimental results showed only about a 3-dB frequency-dependent SNR variation from 5-40 MHz, much less than that observed at higher frequencies. 16-QAM consistently requires 6 to 7 dB more received signal power than QPSK to operate at the same BER. The potential use of high-frequency bands (750-850 MHz) for carrying upstream signals was also examined. The high-frequency transmissions experience more performance variations than low-frequency transmissions, with up to a 10-dB frequency-dependent SNR variation. Attenuation is also much worse at high frequencies.

Our results have the following implications:

The potential for high signal attenuation within the CPN requires that adequate signal strength be delivered to the input of the CPN. This requirement will clearly affect the design of the service provider's network.

Adaptive equalization within the set-top converter cannot be relied on to mitigate all insidewiring problems. Equalization does not overcome 144

excessive CPN signal attenuation caused by excessive splitting or by interference effects from short-time-delay echoes.

Since interference effects vary strongly with frequency, they could easily be overlooked if an installer were to test the performance of only one or a few HFC, MMDS or LMDS channels. Even if testing were performed over a wide frequency range to detect existing problems, CPN characteristics will change as the customer installs new equipment and alters connections or cable lengths.

Consumers need to be educated to appreciate the value of good-quality inside wiring. Retail coaxial splitters should be rated, perhaps with a simple pass/fail based on just a small number of characteristics. Consumers should then be told of the rating, and they should also be encouraged to add terminators on unused cables and splitter ports.

There are a number of potential approaches for minimizing CPN-related service outages and craft dispatches. These include repairing or replacing premises wiring to minimize instances of poor-quality materials and craftsmanship, trading capacity for robustness by using less-aggressive digital modulation formats (e.g., 64-QAM rather than 256-QAM), increasing the transmitted power to deliver stronger signals to the home, or regenerating and remodulating digital signals in a residential gateway at the side of the house. All of these options will effectively raise the cost of broadband digital service delivery. However, with careful planning, an appropriate set of installation, test and maintenance procedures can be developed which will guard against large, unanticipated deployment and life cycle costs.

The optimal approach to premises-wiring problems may vary from one service provider to another, or even from one geographic area to another, depending on the choice of network technology (e.g., VHF/UHF broadcast, satellite, MMDS, LMDS, HFC, or SDV), the nature of the projected service demands, and the resulting tradeoffs between installed first cost and life cycle costs. In any event, the implications of CPN impairments on digital network design, service installation and maintenance practices must be carefully considered to ensure successful deployment of broadband digital services.

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